INVESTIGATIONS OF A 60 KV, 5 CM SPARK GAP FOR SEVERAL ELECTRODE, INSULATOR AND GAS TYPES*

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Abstract

Chemical, electrical and optical measurements were made on a 60kV, 0.05 C/shot spark gap as a function of the number of discharges. The electrodes studied had a spherical surface with a diameter of 5 cm. Several electrode and insulator materials were studied using different gas types at varying pressures. On-line gas analysis, spectroscopy, image-converter and open-shutter photography, voltage and current measurements were taken for the various combinations. Chemical interaction between the electrode, insulator, and gas will be discussed. Discharge characteristics as a function of electrode, insulator and gas type will be illustrated. Also, post analysis of the electrode and insulator surfaces will be discussed.

Introduction

As the requirements for lifetime, rep-rate, high energy and low jitter in spark gaps become more stringent, more detailed understanding of the basic physical and chemical processes that occur in spark gaps is required. Lifetime is affected by erosion, contamination and various failure mechanisms. Increasing rep-rate capabilities requires understanding of the recovery process and removing dissipated energy from the system. Energy and jitter requirements are affected by gap construction and materials, trigger methods, and breakdown processes. The purpose of this current work is to investigate how erosion, recovery, breakdown processes, and failure mechanisms are influenced by choices of electrode and insulator material, gas type and pressure, electrode shape, and trigger methods.

Electrode materials being investigated include brass, a tungsten-copper composite (K-33), and high density graphite. Gases considered are N_2, Air and SF_6. Lucite, blue nylon, and polycarbonate are the insulators under study. A self-breakdown gap with 5 cm diameter hemispherical electrodes is currently operated at hold off voltages of 50 to 60 kV and discharge currents of about 30 kA. Approximately 0.05 C is discharged through the gap during a 2 μs critically damped current pulse giving a 1.5 kJ energy transfer per shot.

On-line diagnostics are used to observe discharge characteristics and to investigate the chemical processes occurring during the discharge. Post analysis is conducted on insulator and electrode surfaces for correlation with the on-line observations.

Experimental Technique

The gap assembly is designed for flexibility to allow quick and easy replacement of electrodes and insulators, adjustment of gap, and operation with a variety of gas types and pressures. Easy accessibility makes it possible to use a variety of diagnostic techniques.

Figure 1 shows a cross-section of the spark gap assembly. The electrodes are 5 cm diameter inserts in aluminum holders. The holders are threaded into supports for quick replacement. The gap chamber is a 25 cm ID aluminum cylinder that contains the discharge region and supports the electrodes and load assembly. Several ports in the cylinder provide diagnostic access and connection to vacuum and gas systems. The large diameter of the aluminum chamber insures that the walls are a reasonable distance from the discharge region and allows a variety of insulator sizes and types to be exposed directly to the discharge region. The upper electrode is adjustable and connects to a 1 Ω solid resistive load. A 0.8 μF capacitor discharges through the gap and load to give a 2 μs critically damped pulse. The gap chamber is connected to a pump for evacuation and to a gas mixing and pressurizing system for the various gas studies.

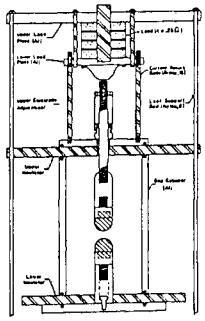

Fig. 1 Cross Section of Gap

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Figure 2 illustrates the major on-line diagnostics used for the spark gap studies. A quadropole mass analyzer is connected to the chamber through a pressure converter sampling system to reduce the sampling pressure from the atmospheric pressure range in the gap chamber to the 10^{-5} Torr range in the mass analyzer sensing unit. The mass analyzer, an Inficon IQ-200, uses a quadropole filter with a 17 stage electron multiplier as a detector. It will detect masses up to 200 amu and is used to observe changes in gas composition as a result of discharges in the gap. At a gap pressure of 1 Atm the sample transit time is approximately 1 s. Thus highly reactive species or nonvolatile substances are not detected by the mass analyzer.

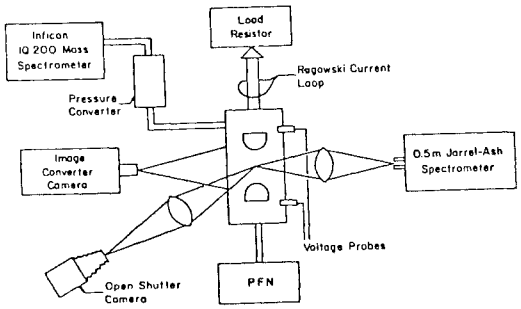


Fig. 2 Spark Gap Diagnostics

Rogowski and Pearson coils are used to monitor the discharge current. Resistive and capacitive voltage dividers are used to study the discharge voltage. A 0.5 m monochromator, an image converter camera and an open shutter camera complete the active diagnostics used to observe the discharge properties.

Analysis techniques used on the electrode and insulator surfaces and on residue collected in the gap include atomic absorption spectroscopy and other qualitative chemical identification techniques. The electrode and insulator surfaces are studied with optical photomicrography, scanning electron microscopy, laser-induced flourescence, and x-ray photoelectron spectroscopy.

Results and Discussion

Investigations have begun on a few of the possible electrode, insulator and gas combinations. Graphite electrodes have been tested under a variety of conditions. The graphite surface shows the least amount of chemical change of all electrode materials examined. No deposits or surface chemicals seem to accumulate on the graphite. The discharge region changes from the original shiny black to a duller grayish white. Individual discharge spots have a circular pattern with a diameter of 4 to 5 mm (1.5 kJ per shot at 1 Atm). The center portion is uniformly lightened while the outer 1 mm of the circular region shows finer black speckled detail. Preliminary analysis failed to indicate a difference in structure or composition between the inner and outer discharge regions. Some increase in the levels of CO and CO_2 in gaps filled with air have been observed and some form of carbon deposits on insulators is noted. Carbon emission lines can be seen in nitrogen filled gaps indicating the presence of some ionized carbon. An erosion rate of about 1×10^{-4} g/C was measured during a total of 2×10^{5} shots. Electron microscope pictures indicate numerous uniformly distributed small (1 to 5 microns) craters and holes (most are roughly circular). Figure 3 is a scanning electron photograph at a magnification of 600 of the graphite surface. A few craters contain non carbon debri that has not been identified to date. Very small cracks are often found connecting the craters. In summary graphite appears to react very little with the filler gas except for possible oxides (CO and CO_2) formed in air. It is also possible that some compounds with nitrogen may form on the surface. The pattern of deposits of carbon on lucite insulator surfaces seems to indicate that most carbon probably is ejected from the electrode in small molecular groups or single atoms, as opposed to large pieces of carbon. Further chemical analysis of the electrode surfaces is in progress.

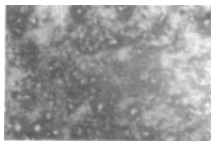


Fig. 3 Graphite Electrode x600

Brass electrodes form surface deposits in pressurized gaps. The principal discharge region (about 1.5 cm diameter) shows a strong structural and/or chemical change. No soluble or scrapable surface deposits appear in this area but inspection under magnification shows definite compositional changes. Apparently the zinc and copper are selectively separated. This is substantiated by the results found by surface analysis of one of the brass electrodes used in this study and reported by L.E. Murr, et al.[1] The electrode they analyzed was the anode. Further analysis of the central discharge region and the insulator deposits will clarify the processes occurring in the direct discharge region. On the remainder of the brass electrode (outside the 1.5 cm region) several chemical deposits (green, blue, and purple) are formed. These deposits are formed primarily in air but to some extent also in CO_2. In nitrogen a black deposit forms. Preliminary analysis by atomic absorption spectroscopy indicates compounds containing zinc and copper and traces of iron and nickel (brass impurities). These deposits (possibly oxides) seem to favor the anode (heavier deposits). Further analysis will indicate the exact composition of these compounds and their distribution.

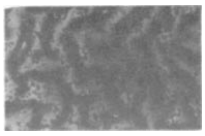
Electrodes of K-33 (66% tungsten and 33% copper) were studied in air. The K-33 definitely shows an elemental migration similar to the brass, but in a smaller region (about 1 cm diameter). The center discharge region is copper colored and is covered with a matrix of small cracks. Surrounding the immediate discharge region is a ring (about 3 mm wide) of dark black deposit. The rest of the electrode surface is covered with a thin, light deposit (much less than brass). These deposits have not yet been analyzed.

Studies of the gases with both mass and visual spectroscopy show a few observable changes. Nitrogen and air show very few changes if any. The water (an impurity) content tends to increase for the first few hundred shots and then gradually decrease to low levels. No insulators were present for the gas studies so the water may be desorbing from the metals and then reacting during discharge to affect a decrease in observed water content. In air-filled gaps with graphite electrodes an increase in CO and CO_2 levels is observed. Also the oxygen content of air may de-

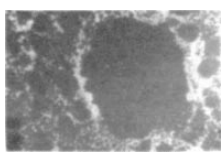
crease very slightly after several thousand shots. More changes are observed in an SF_6-filled gap. Identified so far are decreases in water, SF_6 and SF_5, and increases in SF_4, SF_3, SF_2, and F. Other changes occur at mass numbers that have not yet been identified.

Generally, nitrogen leaves a light blackish deposit on brass and to some extent on K-33. Air gives slightly more reaction with brass and K-33 and some possible interaction with graphite. SF_6 is definitely the most reactive gas. It develops thicker deposits on the metal electrodes, leaves heavy whitish-gray deposits in the lower portions of the cylinder and reacts destructively with aluminum and glass. The SF_6 deposits have been investigated using atomic absorption analysis. So far large amounts of copper, zinc, manganese, iron, chromium and nickel have been identified in these deposits. These metals come from the brass, aluminum and K-33 surfaces. No quantitative results, nor analysis for tungsten or aluminum has been done. A large percentage of sulfur, but no fluorine, is discovered in the SF_6 deposits. This finding is contrary to expected results and warrants further investigation. Also atomic absorption analysis of the surfaces of lucite and blue nylon exposed to SF_6 indicate some sulfur and no fluorine.

So far, only lucite insulators have been extensively exposed to the spark gap environment. When exposed to brass, graphite and K-33 electrodes respectively, the lucite samples develop deposits of whitish green, grayish black, and yellow character. The lucite sample exposed to graphite shows small traces of metals, probably from the surrounding aluminum structure. The lucite sample exposed to K-33 shows copper and some sulfur (although SF_6 was not used - only air and nitrogen). The lucite sample has not yet been tested for tungsten. Scanning electron microscopy yields very interesting differences in lucite samples exposed to K-33 and graphite electrodes. In figure 4 a typical example of each is shown. Lucite exposed to K-33 electrodes show large scale surface changes, apparently due to microparticles from the electrodes. Craters containing metallic impurities are observed. Also long gouges or particle tracks are observed. Particle sizes range from 1 micron to 20 microns in diameter. It is suspected that these consist of tungsten and copper. X-ray photoelectron spectroscopy will be used to verify this.



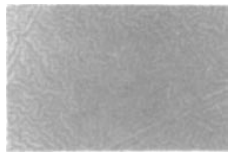
a. Graphite Exposed



b. K-33 Exposed

Fig. 4 Lucite Insulators x2500

Graphite-exposed lucite insulators, however, show no evidence of any particle content or of structural surface damage. The surfaces do seem to show a polycrystalline matrix of carbon deposits. The deposits are very regular and orderly in chains or groups about 2 microns wide and 5 to 50 microns long. The matrix of carbon deposits definitely are affected by machining imperfections and impurities on the surface of the lucite as can be seen by the two straight lines in Fig. 5a. The spaces between the carbon chains are dotted with 0.2 to 0.5 micron particles (probably carbon). The conclusion is that the graphite electrodes are not physically eroded (by melting or by ejection of large particles) but are chemically eroded. The carbon deposits on the lucite can be removed without damage to the lucite surface.



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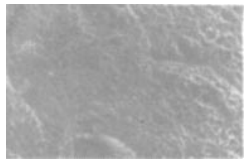

b. K-33 Exposed

Fig. 5 Lucite Insulators x450

So far voltage/current measurements and photography have not indicated any unexpected effects of the gap materials on the physical characteristics of the spark discharge. Pressure and to a small extent gas type affect the diameter of the spark channel and its form (straight or slightly curved). No changes in discharge current or breakdown voltage as a function of electrode material or gas type have been observed yet, besides the characteristic differences in the P-d plots for the various gases. Closer examination of the breakdown portion of the discharge signals may indicate some differences during early breakdown and the resistive phases.

Summary

Investigations of the chemical and physical processes occurring in a 60 kV, 0.05C spark gap are described. Several electrode, insulator and gas combinations were studied and compared. Preliminary results show that metal electrodes (brass and K-33) are more damaging to insulator surfaces than graphite. Also, several surface deposits were analyzed and changes in gas composition were monitored. Definite changes were observed in SF_6 and some in air. Graphite seems to interact chemically with the gases less than brass.

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Reference

1. L.E. Murr, F.L. Williams, D.M. Smith, P. Predecki and S.H. Wang, A Preliminary Survey of High-Energy Switch Materials Degradation Spectroscopic and Microscopic Characterization presented at the 3rd International Pulsed Power Conference in Albuquerque, New Mexico, June 1981.